

APPENDIX D: SUMMARY OF CURRENT INFORMATION ON FIRE REGIMES IN THE KLAMATH REGION

APPENDIX D: SUMMARY OF CURRENT INFORMATION ON FIRE REGIMES IN THE KLAMATH REGION.....	1
1.1. Fire Regimes in the Klamath Mountains: Reconstructing and Interpreting Fire Regimes	1
1.2. Fire Ignitions	3
1.3. Fire Frequency.....	4
1.4. Fire Intensity and Severity	6
1.5. Seasonality	8
1.6. Spatial Extent and Landscape Pattern.....	8
1.7. Additional Concerns About the Reconstruction and Interpretation of Fire Regimes (Dennis Odion).....	10
1.8. Table 1. Summary of fire history studies from the Klamath Mountains and nearby areas of similar vegetation and climate.	12
1.9. Table 2. Summary of fire regime attributes for major forest alliances found in the Klamath Region of northwest California and southwest Oregon	20
2.0. Summary of Fire Regimes in Non-Forest Vegetation	22
A. Chaparral	22
Management Concerns-	22
B. Great Basin Shrublands	24
Management Concerns-	24
C. Bald Hills Vegetation	24
Management Concerns-	25
2.1. Literature Cited.....	25

1.1. FIRE REGIMES IN THE KLAMATH MOUNTAINS: RECONSTRUCTING AND INTERPRETING FIRE REGIMES

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The role of fire in shaping the vegetation and biota of the Klamath Mountains can be assessed by understanding how these ecosystems interacted with fire in the past. Historical conditions or processes are most often characterized in terms of fire regimes, which are described in terms of ignition, frequency, severity, seasonality and spatial extent of fires occurring in a given area (Agee 1993, 1990). Fire regimes can vary considerably by vegetation type and between landscapes, and provide a generally accepted way to categorize areas for study and management purposes (Smith & Fisher 1997, Skinner & Chang 1996, Agee 1994).

Measures of historic fire regimes (e.g. length of fire return interval, severity of fire effects, size of area burned) provide a biophysical baseline – often referred to as “reference conditions” – against which current conditions and proposed management can be assessed. Increasingly, reference conditions derived from historic information are being used to create ecologically justifiable goals for forest management and restoration (Moore *et al.* 1999, Stephenson 1999, Kaufmann *et al.* 1998, Fule *et al.* 1997, White & Walker 1997, Manley *et al.* 1995). However, some researchers have expressed concern that historical conditions may not represent valid reference points for the current climatic period (Millar & Woolfenden 1999). Broad consensus appears to be emerging that managers should use historical ecology to guide the general direction rather than the precise details of restoration treatments (Landres *et al.* 1999).

Most of our knowledge of long-term fire regimes is restricted to what can be derived from analysis of fire scars preserved within the annual growth rings of old trees (Agee 1993, Arno & Sneath 1977). Depending on the spatial extent of sampling, fire histories from fire scar analysis can be related to individual tree, forest stand or landscape scales. Most studies summarized in this report represent stand-level fire histories, meaning that they are based on information collected from multiple fire-scarred trees in an area of several hectares or less. Fire history information for small, specific sites is useful for comparing fire effects within and among different vegetation types, but it does not provide much information on how fire would have influenced landscape dynamics spatial patterns. Very few landscape-scale studies have been completed in Klamath forests (Taylor & Skinner 1998).

Relatively few fire history studies have been completed in the Klamath Mountains compared to neighboring forested regions (e.g. Sierra Nevada, Cascades). Within a particular forest type, generally only a few different sites have been studied, and these fail to represent the full range of regional variability that exists within these forests. Table 1 summarizes fire history information from various published and unpublished sources for the Klamath Mountains and areas in adjacent regions that have somewhat similar vegetation and climate. Data are presented by forest type, based on the dominant tree species reported. The spatial extent of the area sampled is given to facilitate comparison and convey variation in methodologies used. The data summarized represent a period that generally encompasses several hundred years prior to Euro-American settlement.

Not surprisingly, fire histories of the forest types that occur in the region have not been equally studied. Most publications concentrate on the commercially valuable mid-montane Douglas-fir and mixed conifer forests, whereas very little of the literature includes data on foothill/lower montane, upper montane/subalpine zones and forests associated with riparian areas and ultramafic soils. Similarly, some fire regime characteristics (e.g. fire frequency) have been documented much more than others (e.g. fire size, severity). The remainder of this section will summarize what is currently known about each of the fire regime characteristics in the Klamath Mountains, followed by more specific information for the region’s major forest types. Forest types are categorized into general groups based on their elevation range and geographic location.

1.2. FIRE IGNITIONS

Lightning and humans are the two sources of fire ignitions that occurred historically and continue to occur in the Klamath Mountains. Lightning strikes are frequent across most of the region during the summer and have a sufficiently high density to ignite numerous fires (LaLande 1980, Cooper 1939, Morris 1934). Agee (1993) reported that the Siskiyou Mountains exhibit the highest patterns of lightning occurrence in the Pacific Northwest, as much as twice the number of lightning ignitions that occur in either the Cascades or Olympic Mountains (Agee & Flewelling 1983). The higher number of lightning ignitions are due to both increased lightning frequency and decreasing summer precipitation patterns characteristic of the Klamath-Siskiyou region.

July and August have been reported as the months of greatest number of lightning strikes, but August and September have the highest proportion of actual lightning-caused fire ignitions. The low probability of precipitation during the season of lightning occurrence probably allows fires to die down but not be extinguished during periods of low winds or moderate weather, and remain capable of renewed spread under patterns of windier or warmer weather.

Some lightning storms are very localized while others are regional in extent. The regional storms can ignite hundreds of fires almost simultaneously and can easily overwhelm fire suppression capabilities. For example, during the major fire episode of 1987, more than 1,600 lightning strikes were recorded during a twelve hour period in late August in southwest Oregon alone, leading to ignition of 600 fires (Helgerson 1988). These and similar strikes in northwest California led to fires on almost 400,000 hectares in the region (Walstad 1992). According to Atzet *et al.* (1988), essentially all of southwestern Oregon is sufficiently saturated with lightning to ensure that all sites will have the opportunity to burn if fuels are present and dry.

Anthropogenic (human-caused) ignitions have also been important in many forest types of the Klamath-Siskiyou region and can be divided into those started by Native Americans and white settlers. While the exact extent and frequency of Native American ignitions remains unknown, it is clear from historic accounts that most tribes used fire for many reasons. Indian burning appears to have been most frequent in low-elevation oak woodlands, prairies in the coastal forest belt, and eastside ponderosa pine/Douglas-fir forests (Sugihara *et al.* 1987). Aside from these generalities, it is not possible to separate the role of Native American ignitions from lightning sources over the last several thousand years. The most common belief is that while Native American ignitions were locally important, lightning was responsible for a large majority of historic fires and is sufficient to explain long-term fire regimes (Swetnam & Baisan 1996, Agee 1991b, Burke 1979).

After Euro-American settlement, the relatively stable areas of land burned on a regular basis by Native Americans was replaced by accidental and land use fires ignited by white

settlers (LaLande 1995, 1980, McKinley & Frank 1995). Beginning in the mid-1800's and through early decades of 20th century, miners and ranchers were responsible for frequent ignitions, often during periods of extreme summer fire weather. These settlement fires differed in terms of periodicity and seasonality from fires set by Native Americans (LaLande 1995; see section on European settlement). Historical data from 1900 to 1969 for the Rogue River National Forest indicate that between 10 – 60% of fires per year were human-caused (Brown 1960). Contemporary human-caused ignitions tend to occur along travel routes and in highly accessible/developed areas where people are concentrated (USDA Forest Service 1998, 1996, Burke 1979).

1.3. FIRE FREQUENCY

Fire frequency, typically expressed in terms of the fire return interval (FRI), is the most commonly reported attribute of the fire regime. The FRI integrates fire occurrence frequency and fire size to describe the period of time it takes for fire to burn most or all of a unit area of land (Agee 1993). In most fire history studies, multiple fire-scarred trees are sampled at each site, and when fire scars have been dated, the mean or median period of time between all recorded fires is computed. While many studies have reported means as a statistic of central tendency, medians are more appropriate for fire history studies because FRIs are often not represented by a normal distribution (Skinner & Chang 1996). In addition, the pattern of fire return intervals often varies from period to period, and therefore a simple mean may not be representative of longer records (Swetnam 1993).

Some of the data on fire frequency reported for the Klamath Mountains should be interpreted with considerable caution because of methodological problems and potentially erroneous assumptions. For example, fire return intervals reported by Atzet & Martin (1992) and White *et al.* (in press) are based on specific age classes of trees that are assumed to indicate dates of historic fires, rather than on analysis of fire scars. While regeneration of shade-intolerant tree species may be expected to increase after fire, some evidence suggests that tree age cohorts can not be reliably correlated with fire events in the Klamath-Siskiyou region (Stuart & Salazar in press [2000], Tom Sensenig, Medford District BLM, pers. communication). Other variables, such as seed availability, post-fire weather, and variations in soil conditions may also obscure fire-induced patterns of stand development.

Other studies may have produced biased fire return intervals because of a small sample size or restricted location of the study area. The FRI statistic is sensitive to the area sampled, therefore, to make relative comparisons, the spatial scale of sampling has to be taken into account (Agee 1993). The return intervals reported here (Tables 1 and 2) are mostly point or plot composites, which means they are the sum of fire intervals for several to many trees at sites of one to several hectares in size. However, a few studies calculated fire return intervals for significantly larger areas, up to 91 hectares in the Klamath-Siskiyou region (Agee 1991a), and larger for some studies conducted in the southern Cascades. Variation in size of area for which fire return intervals are calculated makes comparisons between some studies problematic.

Given these caveats, available studies indicate that median fire return intervals in forests of the Klamath Mountains vary considerably with forest type, ranging from as high as 140 years in Douglas-fir/mixed conifer forests (van Norman 1998) to 10 years or less in tanoak, jeffrey pine (White *et al.* in press) and ponderosa pine/Douglas-fir (Taylor & Skinner 1994; Table 1). Both subregional and forest type differences are evident, but overall, fires were moderately frequent, averaging between 15-40 years in 19 of the 32 fire return intervals that have been reported. Generally, it appears that fire frequency increases from west to east and from higher to lower elevations (Atzet & Wheeler 1982). Mean or median return intervals for forest types primarily associated with the coastal subregion (coast redwood, western hemlock, and Port Orford cedar) are at least 50 years, and are often likely to be considerably longer. Although no data are presented, Atzet & Wheeler (1982) estimate that the fire-free period varies between 100 – 200 years in the coastally-influenced portion of southwest Oregon. Similarly, Veirs (1985) reports that fire frequency in the North Coast Range of California is much lower than inland areas, due to the maritime influence on relative humidity and fuel moisture. The frequency of lightning ignitions is also known to decrease with closer proximity to the coast (Stuart & Salazar, in press [2000])

Variation in fire return intervals from one study area to another within the same forest type is often significant. Within Douglas-fir/mixed conifer forests, for example, average intervals between fires vary from modal values of 15 years (Taylor & Skinner 1998) to 120 years (van Norman 1998). Furthermore, the large majority of studies show considerable variation in fire frequency within individual study areas. Stuart & Salazar (in press [2000]) report a mean FRI of 39 years for white fir (*Abies concolor*) forests in the western Klamath Mountains, with a range of fire-free periods from 12 to 161 years. Other studies conducted in the region report similarly wide ranges in the intervals between fires, which overall appear to be wider than those from similar forest types in the southern Cascades (Table 1) and Sierra Nevada (Skinner & Chang 1996).

Ecologists have recognized that the variation in intervals between fires at any one site may be more critical than average intervals to understanding the effects of fire over time on vegetation (Taylor & Skinner 1998, White *et al.* in press, Skinner 1997). For example, one 40 year interval between fires on a site is sufficient to allow shade-tolerant tree species (e.g. white fir, incense cedar) to establish and grow to a size where they are relatively fire-resistant (Agee 1993, Taylor 1993, Sugihara & Reed 1987). Fire-free periods of this length have been reported in many Klamath fire history studies, even in forest types with relatively high fire frequency (White *et al.* in press, Taylor & Skinner 1998, Adams & Sawyer 1980). Christensen (1985) proposed that species diversity in many ecosystems may actually depend on such variation. Ecological process modeling (Keane *et al.* 1990) indicates that vegetation and fuels would be significantly different from pre-settlement patterns if fire return intervals were regular, without variation.

The wide variation in fire return intervals characteristic of fire regimes the Klamath Mountains has been attributed to the effects of topography, elevation, weather, fire regimes in adjacent areas, and chance (Moir & Mowrer 1995, Brown 1994, Agee 1991a).

Cursory examination of the data in Tables 1 and 2 suggests that forest types with the greatest variability in fire return intervals tend to occur in more mesic environments and at higher elevations. Moister sites (e.g. coastal areas, canyon bottoms, north-facing slopes and higher elevations) are less likely to have fuels sufficiently dry to burn as on drier sites or south-facing slopes (Heyerdahl *et al.* in press, Teensma 1987, Kilgore & Taylor 1979). Some studies have found at least a weak correlation between topographic variables (aspect, slope steepness, slope position) and fire frequency (Taylor & Skinner 1998, 1997, Key 2000), while others have not (White *et al.* in press, Cissel *et al.* 1999, van Norman 1998). Refer to Tables 1 and 2 and the next section of this report [Appendix] for more information on variation in fire frequencies associated with particular forest types.

1.4. FIRE INTENSITY AND SEVERITY

Fire intensity and severity are two terms associated with the magnitude of fire effects, but have distinctly different meanings in the fire ecology literature. Fire intensity is defined as the amount of energy released from a fire, and may or may not be directly related to effects of fire on the biota. Descriptive measures of fire intensity include the mass of fuel consumed, and the rate of spread of the fire, and the position of the fire front within the forest profile (ground, subcanopy, overstory). The following discussion will focus primarily on fire severity.

Fire severity is a more qualitative measure of magnitude used to describe the degree to which vegetation and site conditions have been altered by a fire. This attribute generally reflects mortality of dominant tree species present in a given area, and is useful in recognizing the variability in fire that occurs within or between fires. Three levels of fire severity are typically recognized in the literature (Agee 1994, 1993, Wright & Bailey 1982):

High severity – Most trees, including overstory trees, are killed.

Moderate severity – Partial stand-replacement fires that include areas of both low and high severity. Some overstory trees are killed or heavily damaged in high severity patches.

Low severity – Light surface fires that have minimal impacts on forest overstories, but may kill small trees and shrubs.

It is usually not possible to measure historic fire severity directly. Inferences are generally drawn based on patterns of fire return intervals, stand age class structures and species composition.

In general, there is an inverse relationship between fire frequency and severity; longer intervals between fires allow for a greater accumulation of fuels that lead to hotter, more severe fires when ignited (Agee 1993). Since most of the forests in the Klamath-Siskiyou region burned at moderate to high frequencies, it follows that most fires produced moderate to low-severity effects on the vegetation. Examination of early historical accounts of fires in the Klamath Mountains generally supports this conclusion (LaLande

1995, McKinley & Frank 1995, Morris 1934). Evidence collected from dendrochronology studies indicates the dominance of moderate or “mixed” severity fires (Tables 1 and 2), where a complex, irregular pattern of tree mortality and openings are created. The patchiness associated with moderate severity fires has been instrumental in promoting species and habitat diversity in the Klamath-Siskiyou region (Sapsis & Martin 1993, Martin & Sapsis 1992).

Within an individual fire, severity is a result of the complex interaction of many temporal and spatial factors including forest structure, fuel availability and moisture, topography, weather, and fire behavior in adjacent areas (Heyerdahl *et al.* in press [2001]). Patches of high tree mortality, ranging in size from individual trees to hundreds of acres, are thought to have been relatively common and occurred in areas with heavy fuel accumulations sometimes reinforced by steep slopes or extreme weather conditions (van Norman 1998, Wills & Stuart 1994, Stephenson *et al.* 1991, Agee 1991a). Fires would be most likely to burn at low intensity during cool nights, periods of mild weather, in areas with low fuel loads, and/or under mesic conditions (Agee 1991b). Larger stand replacement fires probably occurred in moderate severity fire regimes, but at relatively long intervals (>300 years) and likely under extreme fire weather conditions (Stuart & Salazar in press [2000], Atzet & Wheeler 1982).

White *et al.* (in press) found that forest types characterized by low-severity fires (e.g. Jeffrey pine and mountain hemlock series) were generally drier (mean annual precipitation) or cooler (mean annual temperature) than forests with more moderate intensity fires (e.g. tanoak series). They suggested that fire severity may be correlated with forest productivity, because fuels accumulation is more limited in dry and cool environments. Taylor & Skinner (1998) found that fires tended to burn at higher severity on upper slopes, ridgetops and south- and west-facing slopes than lower slopes or east- and north-facing slopes. Fires on sites with rocky or very shallow soils with scattered trees, such as those often found in canyon live oak or subalpine forests, result in little mortality due to lack of fuels (Agee 1993).

These historic patterns of fire severity are consistent with observations of recent fires in wildlands of the Klamath Mountains, many of which continue to burn in a mosaic pattern and result in varying levels of tree mortality. For example, of the 38,200 ha affected by the Silver Fire in southwest Oregon, 9% was high severity, 32% was moderate severity and 59% was low severity (USDA Forest Service 1988). Patches of high mortality were generally less than several hundred acres. The 1994 Dillon Fire on the Klamath National Forest, and the Big Bar and High Fire complexes that occurred in 1999 on the Shasta-Trinity National Forest also burned as primarily low-severity fires with varying-sized stand replacement patches (USDA Forest Service 1999). Additional discussion on the potential change in fire severity from the pre-settlement to contemporary era will be presented later in this report.

1.5. SEASONALITY

The vegetation found within a particular ecosystem has generally adapted over long period of time to the season(s) in which fires generally occur; therefore the seasonality or timing of fire occurrence can be very important in determining fire effects (Skinner & Chang 1996, Agee 1993). For example, spring burning occurs at a time when buds are flushing and are much more susceptible to damage than fires burning in summer or fall (Parker 1987).

The position of fire scars within annual growth rings (e.g. late wood vs. early wood) of trees is commonly used to provide an estimate of the season of past fire occurrence (Dieterich & Swetnam 1984). Data on seasonality of fire is limited in forests of the Klamath Mountains – to date, only a few studies have investigated this fire regime characteristic. In general, seasonal fire scar positions have been found in the latter portions of annual rings, indicating that most fires occurred late in the growing season, from mid-summer to early fall. This is consistent with typical lightning patterns observed in the region, with most of it striking in the late summer (Automated Lightning Detection System 1999).

After being ignited in July and August, many fires appear to have the ability to spread over weeks or months, with periods of smoldering or slow progression alternating with aggressive runs when weather becomes hot or windy. Morris (1934) quotes the Jacksonville newspaper in 1864: “during the past few weeks...the fires [in the Siskiyous] have been raging with increasing fury”. About 70% of recent large fires in the two most northwestern California counties burned during August and September (Gripp 1976). Large fires may burn until autumn rains arrive in October or even later, as was the case with the 1987 wildfires that burned into November (Helgerson 1988).

Although the greatest number of fires and large fire events occur in late summer and early fall, the climate is variable enough to allow occasional fires during favorable periods in the late spring and early summer, particularly on warm, dry sites (C. Skinner, Pacific Southwest Research Station, pers. communication). The more xeric, low-elevation forest types, including interior oak woodland, ponderosa pine, and jeffrey pine are the forests that are most likely to burn early in the fire season, especially those on southerly aspects. The shorter duration of snow cover on south aspects results in longer periods during which fuels are sufficiently dry for fires to ignite and spread (Heyerdahl *et al.* in press [2001]).

1.6. SPATIAL EXTENT AND LANDSCAPE PATTERN

The spatial extent of past fires refers to the size of the area affected by a fire and the landscape patterns that are created as a result (Agee 1993). Fire extent is difficult and time-consuming to determine in ecosystems characterized by mostly low- and moderate-intensity fires, because it requires numerous cross-dated fire scars from a wide area of the landscape, from which deductions of past fire extent can be drawn. But even this

technique is incomplete because such fires would not have scarred every tree within the fire perimeter. In forests that burn with high severity, fire extent may be obvious for a century or more from the mosaic pattern of different-aged stands (Agee 1993).

Relatively few of the fire history studies conducted in the Klamath Mountains have presented data on the spatial extent of fires. Agee (1991a) found that mixed severity fires in Douglas-fir and white fir forests of Oregon's Siskiyou Mountains were historically small to intermediate sizes, ranging from 86 to 576 hectares. Working in similar forest types in northwest California, Taylor & Skinner (1998) reported a mean size of 350 ha. for historical fires, with a range of 28 to 1340 ha, and suggest that large spreading fires are characteristic of Douglas-fir dominated forests in this region. Most of the fires that burned in the 45,000 hectare Little River watershed (near the northern boundary of the Klamath-Siskiyou region) were between 10 and 400 hectares, with a few up to 3,000 hectares in size (van Norman 1998). The dominance of small and intermediate-sized fires in the Klamaths is similar to findings from nearby regions with similar vegetation and climate (Table 1).

The range of variability in spatial extent of historic fires is important in understanding fire as an ecosystem process. Evidence of fire sizes taken from giant sequoia groves in the Sierra Nevada indicates that when fires were more frequent, they appear to have been relatively small and patchy, but during periods of less frequent fires, they were larger and generally more continuous (e.g. drought; Swetnam 1993). Large fire years are often associated with regional events and extreme climatic conditions (McKelvey & Busse 1996, LaLande 1995, Morford 1970). According to Atzet & Wheeler (1982), very large, often stand-replacement fires occur, on average, every 200 years in coastal and western subregions. The 1987 wildfires and 49,000 hectare Big Bar fire complex that burned in 1999 are the most recent examples of this pattern.

It seems probable that the extreme topographic variability characteristic of the Klamath Mountains may help to control the extent and pattern of most fires by inhibiting fire spread (Taylor & Skinner 1998, Swetnam & Baisan 1996, Swanson *et al.* 1988). Forests in this region are typically embedded in and distributed across highly dissected terrain where rivers, ridges, serpentine barrens, and rocky outcrops interrupt the continuity of surface fuels and thereby help to limit fire size (Franklin & Dyrness 1973). In areas where forest types with different fire regimes are closely juxtaposed, the characters of each intermingle and are sometimes indistinguishable (Heyerdahl *et al.* in press [2001], Taylor & Skinner 1998, Agee *et al.* 1990). Local-scale variation in topography can affect the moisture content of fuel by influencing microclimate and can further affect fire regimes by influencing fuel continuity (Taylor & Skinner 1998, Wright 1996, Tande 1979).

The relationship between fire attributes and topography appears somewhat contradictory from the literature, with significant correlations reported in some studies but not others. Taylor & Skinner (1998) found that slopes with south- and west-aspects tended to burn more frequently and at higher severity (Key 2000) than those with north- and east slopes. Similarly, fires were slightly more frequent at low elevations, on ridgetops and steep

slopes in Douglas-fir forests of the North Umpqua Basin (van Norman 1998) and western Oregon Cascades (Weisberg 1998). In contrast, White *et al.* (in press) detected no relationship between fire severity and aspect, slope or slope position in Jeffrey pine and mountain hemlock forests. In the Blue Mountains of northeast Oregon, Heyerdahl *et al.* (in press [2001]) found no difference in fire attributes between aspects where different slopes interfinger without fire barriers.

It is speculative but consistent to infer that variation in topography at the local scale at least partially explains the wide range of fire sizes and large number of patch types that are characteristic of the Klamath-Siskiyou region. Over several decades to centuries, a mid-scale watershed is likely to have experienced considerable shifting of patch locations and types. Some patches may have had dominantly young trees, resulting from areas of high-intensity fire and could be considered early successional; more often patches would be comprised of mixed age classes and species composition, resulting from numerous fire events of varying intensity. Individual trees persisted to old age within many different patch settings, ranging from dense, near even-aged stands of old trees to scattered, even solitary old trees surrounded by shrublands or other non-forest vegetation (Wills & Stuart 1994, van Norman 1998). More landscape-level fire history studies are needed in order to better understand how fire affected vegetation patterns, wildlife habitat and other attributes of ecosystems that occur at larger spatial scales.

1.7. ADDITIONAL CONCERNS ABOUT THE RECONSTRUCTION AND INTERPRETATION OF FIRE REGIMES (DENNIS ODION).

It is important to recognize that understanding of past fire regimes for many forests is complicated by methods and that there may be considerable error in these estimates (reviewed by Baker and Ehle 2001). This problem is illustrated empirically by studies of Jeffrey pine forests in Baja California, which still experience a natural lightning fire regime. Minnich *et al.* (2000) used a combination of aerial photo analyses and field sampling to record fire perimeters. They concluded that 52 years would be required for fire to burn, on average, one time in their study landscape. Periodic fires of variable severity were found to be the spatial process that shaped vegetation patterns and surface fires were small and relatively inconsequential. Analyses of 105 trees that recorded fire scars in the same landscape found that the trees selected for sampling (generally, the oldest, most scarred trees are selected) were exposed to only surface fires that occurred twice as frequently as the average for the whole forested landscape (Minnich *et al.* (2000), Stephens *et al.* 2003). One explanation for the discrepancy is that fire scars may be produced by lightning ignitions that spread very little before they are extinguished. Hence they do not appear on photos. This illustrates the danger of extrapolating from point locations without sufficient understanding of spatial variability. There are other concerns with fire scar data (Baker and Ehle 2001). All the data on forest fire regimes presented in Appendix D are based on fire scar data. The range in historic fire return intervals is likely much greater in portions of the landscapes from which these data were obtained than indicated by the ranges shown.

For many vegetation types (e.g. grasslands, chaparral, high elevation forests), fire is stand-replacing, and there is no record of its frequency. Fire frequency in adjacent vegetation for which there may be estimates may or may not be similar. In addition, tree ring records do not describe past patterns of patchiness created by fire. Thus, it is not possible to have descriptions of patch size or other landscape metrics describing how mixed or high severity fire regimes have structured Klamath landscape. For these and other reasons, precise estimates of past fire regimes, and the vegetation structure that resulted do not exist for heterogeneous landscapes (Veblen 2003).

Complicating matters is the non-equilibrium nature of fire regimes. They have changed constantly throughout the Holocene in the Klamath region. Thus, as climatologists and paleoecologists currently note (e.g. Millar and Woolfenden 1998, Whitlock et al. 2003, Grant and Pierce 2003), reference conditions based on fire frequencies of recent centuries are arbitrary and likely to be unrealistic targets for maintenance because vegetation and fire regimes ultimately track climate. The presettlement Little Ice Age climate has now been replaced by climate that may be warmer than the Mid-Evil warming period, when stand replacing fire was apparently more common in places that were characterized by surface fire regimes during the Little Ice Age (Stephenson et al. 1991, Grant and Meyer 2003).

1.8. TABLE 1. SUMMARY OF FIRE HISTORY STUDIES FROM THE KLAMATH MOUNTAINS AND NEARBY AREAS OF SIMILAR VEGETATION AND CLIMATE.

Area and vegetation	Location	Median or mean FRI ^a	Range of FRIs	Fire severity and extent	Period of record	Type of record	Size of sample area	Source
Klamath Mountains								
<i>Coastal / Lowland Zone</i>								
Western hemlock	NF lands, across southwest OR	~65 ^b	not reported	not reported	1560 -1990	composites of stand origin and disturbance data	0.1 ha plots (51)	Atzet & Martin 1992
Port Orford cedar	NF lands, across southwest OR	~50 ^b	not reported	moderate to high fire severity	1340 -1990	composites of stand origin and disturbance data	0.1 ha plots (18)	Atzet & Martin 1992
Redwood	Prairie Creek, Redwood NP, CA	10 (8)	2 - 37 (2 - 27)	low severity	1714 - 1962	composites of multiple trees	0.25 ha samples over 40 ha area	Brown & Swetnam 1994
<i>Foothill / Lower Montane Zone</i>								
Douglas-fir / tanoak	NF lands across southwest OR	~90 ^b	not reported	> 25% of the area burned may be high severity	1400 -1990	composites of stand origin and disturbance data	0.1 ha plots (195)	Atzet & Martin 1992
Douglas-fir / tanoak	South Fork Salmon River, Salmon Mtns., CA	13 - 22* (10-14)	3 - 71 (5 - 41)	mixed severity	1742 - 1987	composites of multiple trees	3 sites, 5-8 ha each	Wills & Stuart 1994
Douglas-fir / hardwood	Applegate River, eastern Siskiyous, OR	(~17)	12 - 59 (12 - 18)	mixed severity	1760 - 1988	composites of multiple trees, historic photos	2 ha	Agee 1991
Douglas-fir / hardwood	Several areas on Six Rivers NF, CA	13 - 21 (17)	9 - 40 (10 - 40)	mostly low and moderate severity. Number and frequency of fires increased from north to south of study area.	1750 - 1975	composites of multiple trees	39 sites sampled, average of 7.85 ha in size	Adams & Sawyer 1980

Area and vegetation	Location	Median or mean FRI ^a	Range of FRIs	Fire severity and extent	Period of record	Type of record	Size of sample area	Source
Tanoak	NF lands across southwest OR	3 - 23	not reported	no relationship between fire severity and aspect, slope or slope position, but some correlation with elevation. Moderate severity fires occurred at high and low elevations, low severity fires at middle elevations.	1438 - 1998	stand origin and tree age data	0.1 ha plots	White et al. (in press)
Douglas-fir / oak	Oregon Caves NM, central Siskiyous, OR	37	not reported	mixed severity, fire size from 86-576 ha	1480 - 1989	composites of multiple trees, stand origin data	45 ha	Agee 1991
Douglas-fir / tanoak	Eastern Siskiyous, OR	~20	not reported	low to moderate severity	not reported	not reported	not reported	Atzet et al. 1988
Douglas-fir	Little River, North Umpqua Basin, OR	90 - 141 ^c	9 - 362	variable severity, fire size mostly 10-400 ha, few up to 3,000 ha. Fire frequency only weakly correlated w/topography; highest MFIs on low-elevations, ridgetops and steep slopes	1490 - 1996	composites of multiple trees	0.48 ha samples over 45,000 ha	van Norman 1998
Douglas-fir	NF lands across southwest OR	~30 ^b	not reported	low to moderate severity	1200-1990	composites of stand origin and disturbance data	0.1 ha plots (175)	Atzet & Martin 1992
Canyon live oak / mixed conifer	Klamath Mountains (not reported)	13 (11)	7 - 39 (7-33)	not reported	not reported	composites of multiple trees	< 1 ha	Skinner unpublished, reported in Skinner & Chang 1996
Ponderosa pine / mixed conifer	Klamath Mountains (not reported)	11 (11)	3 - 55 (5 - 46)	not reported		composites of multiple trees	< 2 ha	Skinner unpublished, reported in Skinner & Chang 1996

Area and vegetation	Location	Median or mean FRI ^a	Range of FRIs	Fire severity and extent	Period of record	Type of record	Size of sample area	Source
<i>Mid-Montane Zone</i>								
Jeffrey pine / mixed conifer								
Jeffrey pine / mixed conifer	Klamath Mountains (not reported)	12 (12)	4 – 96 (4 – 96)	not reported	not reported	composites of multiple trees	2 ha	Skinner unpublished, reported in Skinner & Chang 1996
Douglas-fir / mixed conifer	Thompson Ridge, central Siskiyous, CA	12 - 19* (12 - 22)	6 - 116 (4 - 200)	mixed severity (86% low and moderate), correlated w/aspect but not slope position or forest type. Mean fire size of 350 ha (28 - 1340 ha)	1626 - 1992	composites of multiple trees	1-3 ha samples over 1570 ha area	Taylor & Skinner 1997, 1998
Douglas-fir / mixed conifer	Klamath Mountains (not reported)	13 (14)	3 – 57 (3 – 52)	not reported	not reported	composites of multiple trees	2 ha	Skinner unpublished, reported in Skinner & Chang 1996
Douglas-fir / mixed conifer	Klamath Mountains (not reported)	12 (15)	3 – 59 (3 – 59)	not reported	not reported	composites of multiple trees	< 1 ha	Skinner unpublished, reported in Skinner & Chang 1996
Mixed conifer	Shasta-Trinity Divide, CA	(17)	(7 - 50)	not reported	not reported	composites of multiple trees	38 sites, ~1 ha each	Skinner 1994 (abstract)
Enriched mixed conifer, riparian	Shasta-Trinity Divide, CA	16 - 42	5 - 71	low severity, significantly lower and more variable than adjacent uplands	1622 - 1933	composites of multiple trees	4 sites, 1-2 ha each	Skinner, in press
Enriched mixed conifer, upland	Shasta-Trinity Divide, CA	7 -13	4 - 64	low to moderate severity	1525 - 1924	composites of multiple trees	4 sites, 1 - 2 ha each	Skinner, in press
White fir / Douglas-fir	Oregon Caves NM, central Siskiyous, OR	43	not reported	low to moderate severity, fire size from 86-576 ha	1480 - 1989	composites of multiple trees, stand origin data	45 ha	Agee 1991
White fir	Oregon Caves NM, central Siskiyous, OR	61 - 64	not reported	low to moderate severity, fire size from 86-576 ha	1480 - 1989	composites of multiple trees, stand origin data	91 ha	Agee 1991

Area and vegetation	Location	Median or mean FRI ^a	Range of FRIs	Fire severity and extent	Period of record	Type of record	Size of sample area	Source
White fir / enriched mixed conifer	Western Marble Mtns., CA	29	not reported	mixed severity; most high severity in young even-aged stands and low severity in old-growth stands	not reported	composites of multiple trees	4 sites along mile-long transect	Thornburgh 1995
White fir	NF lands, across southwest OR	~25 ^b	not reported	not reported	1380-1990	composites of stand origin and disturbance data	0.1 ha plots (296)	Atzet & Martin 1992
White fir	South Fork Mtn. and Bluff Creek, Six Rivers NF, CA	39	12 - 161	most fires of low to moderate severity, w/some high severity. No correlation between MFI and distance from ocean, elevation or latitude.	not reported	composites of multiple trees, across multiple sites	28 sites, 1.2 - 10.9 ha (mean = 4.2 ha)	Stuart & Salazar (in press [2000])
White fir	North-central Klamath Mtns., CA	~25	not reported	not reported	not reported	composites of multiple trees	25 km ²	Taylor & Skinner 1994
<i>Upper Montane / Subalpine Zone</i>								
Red fir	NF lands, across southwest OR	~40 ^b	not reported	not reported	1580-1990	composites of stand origin and disturbance data	0.1 ha plots (40)	Atzet & Martin 1992
Mountain hemlock	NF lands, across southwest OR	~115 ^b	not reported	not reported	1440-1990	composites of stand origin and disturbance data	0.1 ha plots (14)	Atzet & Martin 1992
Mountain hemlock	NF lands across southwest OR	12 - 36	not reported	Generally low fire severity. No relationship between aspect, slope, slope position or elevation with fire severity	1522 - 1998	stand origin and tree age data	0.1 ha plots	White et al. (in press)

Area and vegetation	Location	Median or mean FRI ^a	Range of FRIs	Fire severity and extent	Period of record	Type of record	Size of sample area	Source
<i>Forests on Ultramafic Soils</i>								
Jeffrey pine	NF lands across southwest OR	~50 ^b	not reported	low severity	1540-1990	composites of stand origin and disturbance data	0.1 ha plots (31)	Atzet & Martin 1992
Jeffrey pine	NF lands across southwest OR	7 - 25	not reported	low to moderate severity. No relationship between aspect, slope, slope position or elevation with fire severity	1422 - 1998	stand origin and tree age data	0.1 ha plots	White et al. (in press)
<i>California Coast Range</i>								
Redwood	Bull Creek, Humboldt Redwoods State Park, CA	5-16 (13-31)*	(8 - 87)	Mean fire size was 786 - 1097 ha, not correlated with fire frequency	1726 - 1940	composites of fire scars, basal sprouts and stand origin data	59 plots over 0.80 km ² area	Stuart 1987
Redwood	Olema Valley, Pt. Reyes National Seashore, CA	8 - 13	4 - 17	low severity, w/variable fire size	1750 - 1998	composites of fire scars and stand origin data	not reported	Brown et al. 1999
Douglas-fir / redwood	Barnwell Creek, Interior Coast Range, CA	12 (11)	4 - 22	mixed severity	1819 - 1950	composite of multiple trees	5 sample sites, no size reported	Rice 1990
Douglas-fir	Inverness Ridge, Pt. Reyes National Seashore, CA	8 - 9	1 - 18	low severity, w/ variable fire size	1720 - 1998	composites of fire scars and stand origin data	not reported	Brown et al. 1999
Douglas-fir / hardwood	Elder Creek, Interior Coast Range, CA	13 (6)	6 - 58	mixed severity, with ~50% high severity	1880 - 1983	composites of multiple trees	5 sites, size of area not reported	Rice 1990
<i>Southern Cascades</i>								
Ponderosa pine	Northeastern portion of	17 (4)*	1 - 41	low severity	1501 - 1978	composites of	640 ha	Mastrogiosuippe 1999

Crater Lake NP, OR		multiple trees						
Area and vegetation	Location	Median or mean FRI ^a	Range of FRIs	Fire severity and extent	Period of record	Type of record	Size of sample area	Source
Ponderosa pine	Southern Cascades, CA	16	8 - 32	low severity	not reported	composites of multiple trees	< 10 ha	Olson 1994
Jeffrey pine	Prospect Peak, Lassen Volcanic NP, CA	4 - 6*	1 - 29	low to moderate severity, median fire size of 200 ha (39-792 ha)	1656 - 1994	composites of multiple trees	742 ha	Taylor, in press [2000]
Douglas-fir / mixed conifer	Mill and Deer Creeks, CA	15*	2 - 56	increasing severity and decreasing frequency of fire from lower to upper slope positions	1800 - 1996	composites of multiple trees	11 sites, 0.25 to 3.0 ha each	Norman & Taylor, in press
Mixed conifer / white fir	Annie Creek, Crater Lake NP, OR	17 (16)	4 - 61	low severity, FRIs generally increase with elevation	1748 - 1902	composites of multiple trees	7.5 km ²	McNeil & Zobel 1980
Mixed conifer / white fir	Southern Cascades, CA	9 (10)	3 - 71 (3 - 71)	low severity	not reported	composites of multiple trees	< 10 ha	Olson 1994
Jeffrey pine / white fir	Prospect Peak, Lassen Volcanic NP, CA	5 - 10*	1 - 29	low to moderate severity, median fire size of 167 ha (6-666 ha)	1656 - 1994	composites of multiple trees	753 ha	Taylor, in press [2000]
Jeffrey pine / white fir	Southern Cascades, CA	12 (12)	4 - 157 (4 - 157)	not reported	not reported	composites of multiple trees	2 ha	Skinner unpublished data, reported in Skinner & Chang 1996
White fir / mixed conifer	Caribou Wilderness, CA	14*	not reported	mixed severity, with 13-33% high severity. Mean fire size ~ 128 ha	not reported	composites of multiple trees	506 ha	Taylor & Solem, in press (abstract)
White fir / mixed conifer	Southern Cascades, CA	10 (13)	3 - 24 (5 - 24)	not reported	not reported	composites of multiple trees	2 ha	Skinner, unpublished data, reported in Skinner & Chang 1996

Area and vegetation	Location	Median or mean FRI ^a	Range of FRIs	Fire severity and extent	Period of record	Type of record	Size of sample area	Source
White fir / mixed conifer	Southern Cascades, CA	9 (10)	3 - 26 (4 - 26)	not reported	not reported	composites of multiple trees	2 ha	Skinner, unpublished data, reported in Skinner & Chang 1996
White fir / mixed conifer	Thousand Lakes Wilderness, CA	4 - 9	not reported	> 50% high severity, most remainder moderate severity. Mean fire size 103-151 ha	not reported	composites of multiple trees	2042 ha	Bekker & Taylor, in press (abstract)
White fir	Southern Cascades, CA	9 (11)	4 - 56 (4 - 56)	not reported	not reported	composites of multiple trees	2 ha	Skinner unpublished data, reported in Skinner & Chang 1996
Red fir / western white pine	Prospect Peak, Lassen Volcanic NP, CA	9 - 27*	1 - 46	low to moderate severity, median fire size of 129 ha (11-733 ha)	1751 - 1994	composites of multiple trees	1135 ha	Taylor, in press [2000]
Red fir / mixed conifer	Caribou Wilderness, CA	29 - 35*		mean fire size ~128 ha	not reported	composites of multiple trees	506 ha	Taylor & Solem, in press (abstract)
Red fir	Swain Mountain, CA	16 - 19*	1 - 57	low severity, mostly small fire size (13 – 400 ha)	1740 -1985	composites of multiple trees	3 ha plots and across 400 ha area	Taylor 1993
Red fir	Swain Mountain, CA	40 - 42	5 - 65	moderate severity	1830 -1985	stand origin data	2 plots, 1.0 and 0.48 ha	Taylor & Halpern 1991
Red fir / white fir	Annie Creek, Crater Lake NP, OR	20 (20)	8 - 35 (8 - 35)	low to moderate severity, generally small fire size	1748 - 1902	composites of multiple trees	1 ha	McNeil & Zobel 1980
Red fir	Crater Peak, Crater Lake NP and adjacent NF land, OR	45 (39)	15 - 157 (15 - 71)	mixed severity	1628 - 1988	composites of multiple trees	0.5 ha	Chappell & Agee 1996

Area and vegetation	Location	Median or mean FRI ^a	Range of FRIs	Fire severity and extent	Period of record	Type of record	Size of sample area	Source
Lodgepole pine / red fir	Caribou Wilderness, CA	24*	not reported	mixed severity, with ~50% high severity. Mean fire size larger than in red & white fir forest types.	not reported	composites of multiple trees	506 ha	Taylor & Solem, in press (abstract)
Lodgepole pine / red fir	Thousand Lakes Wilderness, CA	20 - 37	not reported	> 50% high fire severity, most of remainder moderate severity. Mean fire size 405 ha	not reported	composites of multiple trees	2042 ha	Bekker & Taylor, in press (abstract)

^a Values in parentheses are specifically pre-1850 where available. Other values are for entire period of record. Italicized values are means, non-italicized values are medians.

^b Estimates derived from total disturbance history of sampled stands and narrative section of plot data (see Atzet & Martin 1992 for details).

^c Five distinct changes in fire occurrence were identified; 1490-1569, 1570-1844, 1845-1899, 1900-1925 and 1926-1996.

* Indicates statistically significant difference reported for return intervals between pre- (before 1850) and post-settlement periods.

1.9. TABLE 2. SUMMARY OF FIRE REGIME ATTRIBUTES FOR MAJOR FOREST ALLIANCES FOUND IN THE KLAMATH REGION OF NORTHWEST CALIFORNIA AND SOUTHWEST OREGON. This information is the product of a fire science workshop convened by the California Native Plant Society in Redding, CA, April 2000, and is based on the majority of professional opinion of workshop participants. Median fire return intervals and ranges of FRIs in italics are deviations from figures reported at workshop, based on fire history data collected from published and/or unpublished studies conducted in the Klamath Mountains.

Major Forest Alliances by Regional Setting (e) = eastern subregion (w) = western subregion	TEMPORAL			SPATIAL		MAGNITUDE		TYPE
	Median FRIs (yrs)	Range of FRIs (yrs)	Months of fire occurrence	Fire size/extent	Fire complexity	Fire intensity	Fire Severity	Fire behavior
Coastal / lowland Zone (0 to 2,000 feet)								
Coast redwood	<i>10 – 100 ?</i>	5 – 500+	July -October	Small up to thousands of hectares	Very high	low – high	low – high	Surface and passive crown fires
Western hemlock	<i>50 – 75</i>	10 – 200+	Aug – October	Small – intermediate, up to size of stand	High	low – high	moderate	Surface and passive crown fires
Foothill / lower montane Zone (500 to 4,000 feet)								
Oregon white oak (e)	1 – 5	1 – 25	July – October	Small up to size of stand	Low	Low	Low – moderate	Surface fires
California black oak	5 – 20	<i>1 – 40 ?</i>	May – October	Small up to size of stand	Low – Moderate	Low – moderate	Moderate – high	Surface fires
Canyon live oak	<i>10 – 30 ?</i>	5 – 100	May – October	Small up to hundreds of hectares	Low – moderate	low	Low	Surface fires
Knobcone pine	20 – 50	N/A	July - October	Small up to size of stand	Low	High – very high	High – very high	Surface to dependent crown fires
Foothill pine (e)	15 – 50	N/A	May – October	Small up to size of stand	Low – high	Low – very high	Low – high	Surface to passive crown fire
Douglas-fir/tanoak (w)	<i>10 – 30</i>	<i>5 – 150</i>	July – October	Small to tens of thousands of hectares	High	Low – very high	Low – very high	Surface to dependent crown fires
Douglas-fir/canyon live oak	10 – 35	<i>5 – 100 ?</i>	May – October	Small to hundreds of hectares	High	Low - moderate	Low – moderate	Surface – passive crown fires
Doug-fir/ponderosa pine (e)	10 – 20	<i>5 – 55</i>	June – October	Hundreds to tens of thousands of hectares	Low – moderate	Low – moderate	Low – moderate	Surface to dependent crown fires

Table 2, continued

Major Forest Alliances by Regional Setting (e) = eastern subregion (w) = western subregion	TEMPORAL			SPATIAL		MAGNITUDE		TYPE
	Median FRIs (yrs)	Range of FRIs (yrs)	Months of fire occurrence	Fire size/extent	Fire complexity	Fire intensity	Fire Severity	Fire behavior
Mid-montane Zone (3,000 to 6,000 feet)								
Douglas-fir/white fir (w)	15 – 35	5 – 100	August – October	Small to thousands of hectares	Moderate	Low – very high	Low – very high	Ground – independent crown fires
White fir	25 – 65	10 – 160	August – September	Small to hundreds of hectares	High	Low – high	Low – very high	Ground to independent crown fires
Upper Montane / Subalpine Zone (5,000 to 9,000 feet)								
Red fir	40 – 80	5 – 150	August – September	Small to thousands of hectares	High	Low – high	Low – very high	Surface to passive crown fires
Mountain hemlock	100 – 125	50 – 300+	August – September	Small up to size of stand	High	Low	Low – very high	Surface – passive crown fires
Whitebark/foxtail pine (e)	200+	N/A	August – September	Small, single trees or tree clumps	Low	Low – moderate	Low – moderate	Ground to surface fires
Subalpine mixed forest	200+	N/A	August – September	Small, single trees or tree clumps	Low	Low – moderate	Low – moderate	Ground to surface fires
Azonal Forest Types (all elevations)								
Jeffrey pine	40 – 80	10 – 100 ?	July – October	Small up to size of stand	High	Low – high	Low – high	Surface to passive crown fires
Port Orford-cedar	25 – 80	10 – 200+	August – October	Small up to size of stand	High	Low – high	Low – high	Surface to passive crown fires

2.0. SUMMARY OF FIRE REGIMES IN NON-FOREST VEGETATION

A. Chaparral

Chaparral dominates the lower elevations of Whiskeytown. This vegetation is a dense evergreen shrubland that is capable of tolerating more extreme summer drought than forest vegetation. Waring et al. (1978) have described the moisture stress beyond which conifer vegetation is intolerant. In the eastern Siskiyous, this commonly occurs on sites below 1,000 m. At Whiskeytown, more severe summer drought allows chaparral to extend to higher elevations. Considerable areas at mid elevations of Whiskeytown, or relatively moist slope positions at lower elevations are characterized by a mixture of chaparral and oak and pine vegetation. Chaparral is also the early successional vegetation at higher elevations where conifer forest is the potential natural vegetation. In these circumstances, chaparral is generally replaced by conifer vegetation after 50-100 years in the absence of stand replacing disturbance. This variant is often referred to as montane chaparral.

In southern California, it is well known that chaparral burns almost exclusively by crown fire. The fire ecology of chaparral in northern California and southern Oregon has been little studied in comparison. The research by Sampson (1944), who worked as far north as Shasta Co., suggests that, during wildfires, lower elevation chaparral, such as at Whiskeytown, would naturally burn primarily by crown fire. Montane chaparral at higher elevations may burn with mixed severity (Odion et al. in press), but stand-replacement is still common.

Chaparral plants do not provide a record of fire like some conifers. Thus, the historical frequency of fire in chaparral can only be inferred from other evidence. The frequency of fire in adjacent vegetation (Tables 1-2) can provide some inference, but uncertainty in estimates based on fire scar analysis are an issue. As described below, non-sprouting chaparral species, which are highly specialized to fire, are vulnerable to fire as frequent as estimated by many fire scar analyses (see section 2). These species are ubiquitous in chaparral in the Klamath region. This further suggests that fires in the past may have been less frequent than estimated by fire scar methods across much of the landscape.

Management Concerns- Over much of the range of chaparral, like many other shrublands worldwide, non-sprouting shrubs that are endemic to this vegetation are threatened by too frequent fire (Odion and Tyler 2002, Russell-Smith et al. 2002). This is because fire-free periods have shortened as a result of anthropogenic burning and invasion of exotic species that increase the combustibility of the shrublands when they are regenerating from fire. While fire is not presently too frequent in the Klamath region, it could become so locally where human ignitions increase and where extreme fire weather is common. This scenario could be realized in the vicinity of Whiskeytown.

Without sufficient time to replenish seed banks, non-sprouters can be eliminated by fire free periods that are short. In chaparral, annual grasses now often invade following fire, allowing for early reburns which have been found to replace the shrub vegetation with annual grassland as described below (Zedler et al. 1983). Research on a number of nonsprouting shrubs in chaparral has documented risk due to fire-free periods that are too short, but there is no evidence of a risk

due to senescence in the absence of fire among species that have been studied (Zedler 1995, Keeley 2000, Odion and Tyler, 2002). The commonly accepted premise that chaparral becomes decadent with long fire-free periods has been shown to be generally false, and referred to as the “myth of stand senescence” in a recent review on chaparral (Keeley 2000), although forage available to deer may decrease if a greater proportion is beyond their reach. Moreover, fuel loading has been found not to be reliably predicted by stand age (Payson and Cohen 1990). Fire has been shown to burn readily through chaparral of any age class, at least if hot dry winds occur (Moritz et al. 2004). And, mature chaparral is resistant to invasion by exotic species. Considering these factors, Keeley (2002) pointed out that prescribed burning does not provide any resource benefit, is risky, and he recommended against it.

Another problem with prescribed burning in chaparral concerns the timing. Research has shown that moistening seed of chaparral plants that are not hard-seeded (i.e. species other than *Ceanothus* and most legumes) causes them to completely lose their heat tolerance (Sweeney 1956, Parker and Roger 1987). These seeds take up moisture seasonally, and as they dry out in summer, they become tolerant of high levels of heating. Seeds are likely to be especially vulnerable to burning after soils have been moistened in fall, but before fuel moisture has risen appreciably, because considerable heat could still be generated by fire at this time. Thus, burning under these conditions is likely to produce unnaturally high seed mortality and result in artificially low seedling emergence (Parker and Roger 1988). This would have adverse, long-term impacts in stands lacking resprouting species. On the other hand, if soils are really wet at the time of fire, and fireline intensity is relatively low, little soil heating will occur (DeBano et al. 1979). In this situation, hard-seeded species may not receive sufficient heat shock to germinate, resulting in a similar impact scenario. It is unclear which other species would be cued to germinate. Thus, out of season burning in areas dominated by non-sprouting shrubs (*Arctostaphylos viscida*, *Ceanothus integerrimus*, *Ceanothus cuneatus*, and in conifer forests, *C. velutinus* and *C. prostratus*), may have poor regeneration of shrubs and other fire-recruiting species. Populations of species with fire-dependent recruitment (in the absence of soil disturbance) will be reduced as a result, and seed banks will be depleted. Thus, out of season burning can also reduce fire annuals and short-lived fire followers because their seed may not be present to germinate following the next fire at the site, and it does not disperse in from surrounding areas. These species are not likely to be resilient to these effects. Another factor that can contribute to reduced post-burn shrub recruitment is spring burning followed by rainfall sufficient to induce germination of surviving seeds. Seedlings that establish from such late germination have been found to have greater mortality during their initial summer (Moreno and Oechel 1993).

Burned areas of poor shrub regeneration will be more prone to invasion by yellow starthistle, cheatgrass and other annual grasses. The fine fuel of these annual grasses can carry fire and allow for a reburn before shrubs have begun to produce seeds. Also, mortality of young resprouts can occur, and shrubs are often too depleted to resprout again. Thus, such successive, short rotation (<5 years apart) fires can largely eliminate chaparral (Zedler et al. 1983). The shallow-rooted and quickly curing grass and weed vegetation that replaces chaparral under such type conversion will ignite more easily over a longer portion of the year, spread fire more rapidly, make slopes vulnerable to a future regime of more frequent fire and disturbances related to reduced slope stability in the absence of deep rooted shrubs.

B. Great Basin Shrublands

Sagebrush, juniper, and rosaceous shrubland dominate much of the landscape at Lava beds. Rosaceous shrubland is composed of deciduous species with relatively soft leaves lacking obvious drought adaptation of chaparral sclerophylls. The Rosaceous shrubland also appears to differ by not being a crown-fire dependent vegetation like chaparral. Sampson (1944) did report a 4 times increase in germination rates for western chokecherry (*Prunus virginiana*) when seeds were heated to ~105°C, but germination also occurred without fire effects. Most of the dominants of the rosaceous shrubland are found throughout the Great Basin in an association sometimes referred to as petran chaparral. The dense nature of the shrubs/small trees, with interlocking crowns, resembles typical chaparral architecturally, but in other respects this is functionally different vegetation. Rosaceous shrubland at Mesa Verde National Park, a rocky environment, is believed to burn very infrequently (~400 years) despite a particularly high frequency of lightning (Romme et al. 2003).

In sagebrush and juniper vegetation, the junipers are, in places, increasing in density and expanding into adjoining sagebrush shrublands and grasslands. This is believed to be caused by fire exclusion, livestock grazing, and climate change. Baker and Shinneman (2004) systematically reviewed the literature for available evidence to help determine which factor is most important or how each factor has contributed to change. While fire, is believed by many to have been frequent enough, prior to fire suppression, to have maintained low-density pinyon-juniper savannas and woodlands in some areas and to have prevented tree invasion into sagebrush and grasslands evidence of low-severity surface fire is lacking because the trees do not reliably record fire scars. Conversely, there is evidence that fire regimes in sagebrush and juniper vegetation in many areas consisted of mixed and high-severity fires and that these fires, though perhaps infrequent, structured the vegetation. There is also evidence that climate fluctuations have favored juniper expansion (Soule et al. 2004). In eastern Oregon, Soule et al. studied juniper establishment in disturbed and undisturbed areas and concluded that The driving forces explaining the late 1800s to early 1900s pulse of establishment for western juniper are livestock grazing and favorable climatic conditions, while absence of crown fire has allowed disturbance facilitated cohorts to persist.

Management Concerns- There is concern about juniper expansion into sagebrush at Lava Beds. However, imprecise knowledge of past vegetation structure, and fluctuation in juniper abundance with infrequent high severity fire along with climate change makes identification of appropriate and realistic restoration targets difficult. In addition, mechanical removal of trees may have detrimental impacts to wildlife and other resources. Baker and Shinneman conclude that “local research is essential, at the present time, if effective, scientifically based restoration prescriptions are to be derived.”

C. Bald Hills Vegetation

Bald hill grassland and oak vegetation occurs on hilltops in Redwood National Park. This vegetation has been studied by Sugihara et al. (1987). It is estimated that Native Americans regularly set fire to these bald hills for 6,000 years. Frequent burning can prevent the

establishment of woody plants. Following the demise of Native Americans, fire has largely been absent from the bald hills. In addition, the bald hills have been grazed by livestock and invaded by exotic grasses. Successional changes in the absence of fire and grazing in the bald hills takes two forms. In relatively xeric interior areas, succession is from grassland and oak savanna to mixed evergreen forest that includes tanoak and Douglas-fir. In more coastal and mesic areas redwood forest with Douglas-fir may replace open oak and grassland vegetation.

Management Concerns- It is not clear what the frequency of fire and the vegetation would have been in the past without native American impacts, nor to what extent climate change may be influencing current dynamics toward more woody vegetation.

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